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SOURCES OF ENERGY
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Item 3 of the provisional agenda*

SUBSTANTIVE THEMES SELECTED FOR DETAILED DISCUSSION

Contribution of new and renewable sources of energy to integrated rural development, including the utilization of agricultural residues for energy production

Note by the Secretary-General

1. The Committee on the Development and Utilization of New and Renewable Sources of Energy, at its fourth session, decided to include in the provisional agenda for its fifth session, for detailed consideration, the theme of the contribution of new and renewable sources of energy to integrated rural development. 1/ By resolution 43/192, the General Assembly endorsed the resolutions and decision contained in the report of the Committee on its fourth session and invited interested States, organizations of the United Nations system and other interested organizations to convene technical and scientific meetings, related to the substantive themes, that would contribute to the examination of such themes in depth, and to inform the Committee, at its fifth session, of the results of those meetings. Accordingly, the report of the United Nations Group of Experts on the Role of New and Renewable Sources of Energy in Integrated Rural Development, held at Stockholm from 22 to 26 January 1990, is annexed to the present note. The meeting of the Group of Experts was sponsored by the Swedish Agency for Research Co-operation with Developing Countries (SAREC) and organized by the Department of International Economic and Social Affairs of the United Nations Secretariat and the Food and Agriculture Organization of the United Nations (FAO).

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* A/AC.218/1990/1.

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2. It may be noted that document A/AC.218/1990/5 contains a description of the activities carried out by entities within the United Nations system in relation to the role of new and renewable sources of energy in integrated rural development, as also requested by the Committee. 2/

Notes

1/ Official Records of the General Assembly, Forty-third Session, Supplement No. 36 (A/43/36), annex, resolution 1 (IV), para. 1.

2/ Ibid., para. 5.

Annex

REPORT OF THE UNITED NATIONS GROUP OF EXPERTS ON THE ROLE OF NEW AND RENEWABLE SOURCES OF ENERGY IN INTEGRATED RURAL DEVELOPMENT STOCKHOLM, 22-26 JANUARY 1990

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I. BACKGROUND

1. The United Nations Conference on New and Renewable Sources of Energy was held at Nairobi in August 1981. It adopted the Nairobi Programme of Action for the Development and Utilization of New and Renewable Sources of Energy, a/ with the main objective of promoting concerted action for the development and utilization of new and renewable sources of energy to help meet future energy requirements, especially in developing countries.

2. The Conference identified five broad policy areas for concerted action, with the support of the international community according to national plans and priorities: energy assessment and planning; research, development and demonstration; transfer, adaptation and application of mature technologies; information flows; and education and training. b/

3. In resolution 36/193, section I, the General Assembly endorsed the Nairobi Programme of Action. By resolution 37/250, section II, the Assembly decided to establish an intergovernmental Committee on the Development and Utilization of New and Renewable Sources of Energy and charged it with responsibility for guiding and monitoring the implementation of the Nairobi Programme of Action. The Committee has held four sessions.

4. At its fourth session, in March 1988, the Committee decided on three themes for detailed consideration at its fifth session, in 1990, one of which related to the contribution of new and renewable sources of energy to integrated rural development. c/ The Committee requested the Secretary-General to prepare a report for consideration by the Committee at its fifth session, based on an in-depth study of the current achievements of States regarding this theme. The Committee invited interested States and organizations to convene technical and scientific meetings related to the theme that would contribute to its in-depth examination.

5. In implementation of the Committee's decision, the United Nations Group of Experts on the Role of New and Renewable Sources of Energy in Integrated Rural Development was convened at Stockholm in January 1990. The meeting of the Group was sponsored by the Swedish Agency for Research Co-operation with Developing Countries (SAREC) and organized in co-operation with the Department of International Economic and Social Affairs of the United Nations Secretariat and the Food and Agriculture Organization of the United Nations (FAO).

6. The following topics were discussed:

(a) Integrated rural development:

(i) Definition and goals of integrated rural development;

(ii) Energy for integrated rural development;

(b) Energy supply and demand in rural areas:

(i) Demand considerations (household, agriculture, rural industry, transport, economic, social, climate, others);

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(ii) Assessment of energy needs of rural and agricultural activities;

(iii) Assessment of energy needs for cottage activities, village enterprises and rural industries;

(iv) Supply considerations (traditional, conventional, new and renewable);

(c) Energy options and considerations for rural and agricultural development:

(i) Technological options:

Efficient energy use;

Fuelwood;

Conventional sources;

New and renewable sources;

(ii) Socio-economic considerations:

Energy consumption, distribution and quality of life;

Socio-cultural issues;

Participation in the formulation and implementation of plans;

Women's role in rural development and rural energy development;

(iii) Environmental issues and impact:

Environmental problems associated with energy production and use in rural areas;

Policies and measures designed to minimize adverse environmental impacts of rural energy development programmes;

(d) Energy investments and pricing policies:

Energy investment requirements and methods of financing;

Energy pricing for integrated rural development;

Role of the local private and public sectors;

Role of multilateral and bilateral assistance programmes;

(e) Action to promote renewable energy sources for rural and agricultural development:

Energy assessment and planning (integration of rural and agricultural

energy needs into national energy, rural and agricultural development plans and programmes);

Technological development (identification of priority research, development and demonstration activities in the light of the present and future international energy scene);

Institutional aspects;

Investment aspects;

Information flows;

Environmental issues;

(f) Country or regional experiences.

7. Technical papers were presented by experts from both developed and developing countries, as well as from academic institutions and United Nations bodies. d/

8. The highlights of the discussions and conclusions of the meeting as agreed to by all the experts participating are set out below (for the list of participants, see the appendix to the present report).

II. OPENING STATEMENTS

9. In welcoming the participants, the Director-General of SAREC said that allocations of 47 million Swedish kronor in energy research over the past 15 years had been devoted to renewable energy sources and technologies as well as energy policy and planning. The focus of this support had been Africa south of the Sahara. The latest initiative was the support given to the African Energy Policy Research Network.

10. In opening the meeting, the Under-Secretary of State, Ministry of Foreign Affairs of Sweden, said that in the decade that had elapsed since the adoption of the Nairobi Programme of Action not much progress had been made in the development and utilization of new and renewable sources of energy. In the past few years, however, there had been increasing awareness of the interrelationships of development issues, particularly with regard to poverty in developing countries, energy development and the global environment. At the same time, there was increasing realization that an integrated approach was required in efforts to arrive at solutions of complex problems with global dimensions.

11. He said that the beginning of the 1990s had been accompanied by new hopes for world peace, with prospects for military cutbacks that could result in a sizeable "peace dividend", thus freeing considerable resources, part of which should be directed towards economic and social development in developing countries.

12. He noted the greatly improved role of the United Nations in political aspects and called for the strengthening of the Organization in the economic and social fields.

13. The Assistant Secretary-General for International Economic and Social Affairs of the United Nations Secretariat said that energy was essential to the development process. Economic development was basically the mobilization of various forms of energy, partly to replace human or animal work, partly for totally new uses. Energy was not just another element in the production process; in a broad sense, it was the life blood of the biosphere itself.

14. The Nairobi Programme of Action recognized that in rural development energy was a priority. Rural areas needed energy for cooking, heating, lighting, water supply, cooling, refrigeration, modernization of agricultural cultivation and rural industry. But in developing countries, most of the energy in rural areas came from traditional sources such as fuelwood, crop residues and dung. Commercial sources such as coal, oil, and gas accounted for less than 25 per cent of rural energy consumption.

15. The population was growing fast in both rural and urban areas and the pressure on traditional sources of energy, such as fuelwood, was excessive and environmentally destructive in many parts of the world. The pressure was not expected to lessen in the foreseeable future, in spite of the great migration to urban areas.

16. In 1981, at the time of the United Nations Conference on New and Renewable Sources of Energy, it had been widely expected that the price of oil would continue to rise, which had generated increased interest in new and renewable sources of energy. However, even before the sharp drop in oil prices in 1986, interest in new and renewable sources of energy had waned. There had been major cutbacks in funding and related activities.

17. So far, for a number of reasons, new and renewable sources of energy had failed to meet their promise in rural areas. First, many of these technologies had not yet become economically competitive with alternative energy sources. Secondly, there had been a lack of policy support, in many instances arising from the general neglect of the rural sector and that had contributed to the paucity of investment in projects to develop new and renewable sources of energy in rural areas. Thirdly, a number of technologies had not been readily accepted because their introduction had not fully taken into account the socio-cultural context of their application in rural areas. Lastly, rural poverty, which largely ruled out commercial energy sources, might make it difficult to undertake even very modest investments in new and renewable energy, especially in the absence of government interest.

18. But a number of technologies to develop such sources of energy had been quite successful. Examples included small-scale hydro plants for electricity generation, wind pumps, biogas plants for cooking and lighting, and photovoltaic units for lighting and refrigeration. The world-wide contribution of new and renewable sources of energy in 1985 was more than 1 billion metric tons of oil equivalent. That figure represented slightly over 13 per cent of total energy supplies, a little less than natural gas, and more than three times as much as nuclear energy. In the developing countries, new and renewable sources of energy provided an average of 30 per cent of energy consumed. In Africa it was as high as

57 per cent, in Latin America 33 per cent and in the Asia and Pacific region 22 per cent. e/ In rural areas alone the contribution of new and renewable sources of energy was much higher.

19. These technologies were still in their infancy - their potential appeared to be considerable. But many things would have to be done to exploit that potential. There had to be greater participation by users, more information about new technologies and, above all, more investment. New and renewable sources of energy had not, as yet, found their rightful place in national energy plans and strategies. Energy investments should go hand in hand with economic development, bearing in mind the long lead times of energy projects, since energy shortages in many developing countries had been causing considerable loss of income. In that context, rural energy needs were even more vital. Governments had an essential role to play in charting future needs and ways to meet them, and they should explore all channels, private as well as public.

III. ENERGY CONSUMPTION AND SUPPLY

20. At the beginning of the last decade of the twentieth century, energy consumption in the rural areas of developing countries continues to be dominated by traditional sources, especially biomass. Consumption of fuelwood has been increasing rapidly because of fast population growth, which has sometimes resulted in the clearing of forests for more food, thus reducing wood supplies. Regional climate change and desertification have compounded the problem.

21. While oil consumption has been limited in the rural areas of the developing countries, higher prices since the early 1970s have contributed to the energy and economic crises, especially if account is taken of higher costs of other agricultural inputs such as fertilizers and pesticides. The more recent economic crisis of deep indebtedness has also accentuated poverty in the developing countries, including rural areas, with consequent repercussions on their energy situation.

22. In these circumstances, biomass fuels are being consumed faster than they are being replenished, foreboding even more serious problems in the future. Efforts to alleviate this situation have concentrated on a variety of measures to promote more efficient use of the limited supply of available energy resources, particularly with regard to household appliances and equipment for irrigation and general farming. For a variety of reasons, including the initial cost and limited social acceptability, experience with technically efficient cook stoves has been disappointing in many developing countries. There have been successes in a few developing countries, however, notably China and India. Similarly, reforestation programmes have generally failed to arrest, let alone reverse, the deteriorating situation.

23. Pressure on the rural biomass supply is further aggravated by the increasing demand of urban residents for fuelwood. Because of this demand, deforestation has often been more widespread near growing urban centres.

24. Efforts to develop local commercial energy supplies, such as small coal mines and mini hydro plants, have been successful in a few countries with appropriate natural resources and social organizations for the provision of the necessary capital, technology and trained manpower. Small oil and gas fields have, in some cases, made similar contributions. For the majority of the developing countries, however, higher oil import costs have been translated into higher prices for petroleum products, such as kerosene, which are widely used in rural areas. More recent measures to cut or eliminate subsidies for petroleum products have aggravated the situation.

25. The deteriorating position of traditional as well as conventional supplies has led to increasing attention being given to other technologies, such as solar cells and windmills, which promise decentralized and therefore more appropriate rural energy. However, despite significant technological advances with consequent reductions in cost, their application has been experimental and quite limited. High capital requirements will have to be cut substantially before widespread use can be expected.

26. Governments and development agencies have been concerned with the deteriorating environmental conditions related to rural energy supplies, especially as they are expanded in order to promote rural economic development. This concern has been heightened by the potential for global climate change due to the increase of the so-called greenhouse gases, from increased burning of fossil fuels, deforestation and so forth. This concern may lead to increased efforts aimed at the more efficient utilization and increased supply of appropriate rural energy.

27. The task will be enormous since it is estimated that of a total population of 3.6 billion (1985) in the developing world, 60 per cent or 2.2 billion have no access to electricity.

28. In analysing the rural energy situation, it is important to bear in mind that rural areas in the developing countries are highly heterogeneous. Rural people live and work in diverse and widely varying ecological and social settings even within a single country. The rural energy patterns and changes are affected by diverse cultural, social, political and economic contexts. Within each rural community, there will often be diverse or even divergent interests.

29. With a few exceptions (e.g., China), conventional energy sources such as coal, oil and gas are generally not locally available in the rural areas of the developing countries. These areas have also generally not been adequately explored for such resources. The cost of imports are high especially in relation to the very low incomes of rural people. Rural electrification programmes have had limited success because of high costs for interconnections and high capital requirements and operating costs of independent electricity supply systems (e.g., diesel power).

30. Apart from hydraulic energy, which, however, is often classified as a conventional energy source, biomass constitutes the most important renewable energy source. Biomass resources include organic wastes, natural forests and energy crops.

31. Considerable advances have been made in technologies for the development of new and renewable sources of energy and they are now mature enough to be applied in rural areas. These technologies include photovoltaic and wind systems and a variety of new technologies which convert biomass into secondary energy forms and more efficient energy use through such devices as cookstoves.

32. Energy resource assessments are of particular importance in rural areas for proper planning. In assessing energy sources in rural areas, consideration should be given to all sources, conventional as well as new and renewable. Assessment surveys of rural energy supplies have, however, met with a variety of difficulties, including, in the case of biomass, lack of standardized methodologies and trained personnel as well as unsatisfactory participation of rural energy consumers who often possess the necessary information. Solar and wind energy assessment problems involve information gaps, access and availability of monitoring equipment.

33. There is a need to adequately address the problems of assessment and measurement. Optimal use should be made of the information and know-how normally available within national meteorological services and other relevant institutions. At the same time, an appropriate balance is required between the need for accuracy and comprehensiveness in the collected data and the imperative for action.

34. Knowledge of existing natural forest resources and their productivity under management for sustained yield is generally poor in developing countries. Methods for their management for sustained yield exist in only a few cases. A similar situation applies to the possible production of artificially generated (planted or sown) forest stands, for which there is, to some extent, some knowledge in medium to high productive areas but little information in the low productive, semi-arid areas.

35. Rural energy consumption has been dominated by the household sector and rural energy surveys have tended to ignore other important sectors such as agriculture, local industry and transportation. Many of the surveys undertaken have covered specific geographical areas and time periods, with the result that extrapolations to cover the whole country or forecasts for future demand are often misleading.

36. In order to evaluate rural energy needs properly, it would be necessary to improve survey techniques to include detailed end-use information, which requires the participation of consumers. In this context, energy analysis should also focus on changes that take place over time because of important shifts in patterns of both rural energy requirements and supplies, particularly during periods of abrupt economic change.

IV. TECHNOLOGICAL OPTIONS

37. Over the past two decades, numerous technical options for the generation and distribution of energy for agricultural and rural development have been developed and field tested in a large number of developing countries. The results of many such initiatives have often been below expectations, one of the main reasons being the unexpected complexity of developing, selecting and implementing appropriate options that adequately address the rural energy question.

38. The scarcity and difficulty of obtaining information on the rural energy sector constitute important constraints in the selection and diffusion of appropriate technological options. Much of the available information is geared to the needs of decision makers but not to personnel in the field. Past attempts to collect data on rural energy have often been static in nature and content: the data collected provided a snapshot of the energy situation but were not able to capture the dynamic and fluid nature of rural energy. Part of the problem is that those active in the field belong to many different disciplines or do not publish or otherwise make available information on their work.

39. Past attempts at addressing the rural energy question tended to focus on specific technologies for generating energy; for example, a micro-hydro plant or a biogas plant. As a result, current understanding of how stand-alone energy technologies perform is not matched by an adequate appreciation of the institutional environment that is necessary for the successful introduction of rural energy technologies.

40. It is necessary to adequately address basic needs in rural areas. In particular, special effort should be directed towards enhancing equity in these areas. The introduction of rural energy technologies is not in itself sufficient to address the question of equity. In certain cases, rural energy technologies may widen income gaps instead of narrowing them.

41. Of increasing concern at the level of research and development is also the gap between developing and developed countries, which is large and growing. Of critical importance in the development and wide-scale dissemination of rural energy technologies is the need to address the requirements of users and ensure their full participation. In this respect, rural energy technologies are no different from the more conventional technologies. In both cases, user needs are paramount and user participation is an essential component of technology development. User needs and participation are now prerequisites for the successful implementation of rural energy technologies. It is important to encourage efficient energy use and local manufacture of such technologies. These questions are discussed below.

Efficient energy use

42. Energy conservation has several intrinsic advantages. First, it does not entail the high investment and costly financial outlay of exploration and energy production. Secondly, it is generally not equipment or machine intensive. Energy conservation is, however, information intensive. It requires an in-depth understanding of current energy use patterns in order to identify the most cost-effective and promising conservation opportunities. It should be noted that the choice of certain construction materials could lead to savings in energy, as could the appropriate design of rural dwellings. The application of conservation technologies has, however, had limited results.

Fuelwood

43. An estimated 2 billion people, many of whom reside in rural areas, depend on fuelwood to meet their cooking and space heating needs. Other rural uses of fuelwood include charcoal production, post-harvest crop processing (e.g., tea

drying and curing of tobacco) and brick manufacture. Fuelwood technologies that have been developed to date can be subdivided into three categories: production and supply; conversion and end-use. The research and development work in these categories has focused more on enhancing the efficiency of the three processes mentioned above than on the systematic development of innovations.

Conventional sources

44. Conventional energy sources for rural development include large-scale hydropower, coal, and petroleum products such as diesel and kerosene. Being relatively better established, conventional energy technologies do not suffer as much from the shortage of trained manpower for installation, operation and maintenance of associated equipment and the lack of infrastructure. However, conventional energy technologies are heavily dependent on external inputs either in the form of fuel (petroleum) or machinery or spare parts. As a result, these technologies require access to adequate imports. With most of the developing countries facing chronic shortages of foreign exchange, the continuity of service for rural areas by means of conventional energy technologies cannot always be assured.

New and renewable energy sources

45. By the early 1980s, a number of technologies to develop new and renewable sources of energy had demonstrated an unexpected level of success in addressing energy problems faced by agriculture and development initiatives in rural areas. In particular, the following technologies have shown a promising level of performance in rural areas: (i) small hydro plants for shaft power and electricity generation, (ii) wind pumps for water lifting, (iii) biogas plants for cooking and lighting, (iv) photovoltaic units for lighting and refrigeration, (v) solar thermal energy and (vi) improved stoves.

Contribution of agricultural residues

46. Agricultural residues are divided into two broad categories: (i) crop residues including woody residues, crop straws, green crop residues and crop processing residues and (ii) animal residues such as cow dung and poultry and pig manure.

47. Large quantities of residues are produced in the developing countries. The actual quantity produced depends on agricultural practice. The use of the residues depends on bulk and density as well as the cost of the logistics and collection. The main consuming sectors in rural areas are households, agriculture and industry. The extent to which each sector uses agricultural products depends on many factors, including (i) the agricultural mix - some crops generate residues low in energy value; (ii) agricultural practices - in some countries these involve clearing large areas of forest or woodlands for farming; (iii) the scarcity of other fuels - residues tend to be substituted for wood fuels; (iv) the energy demand pattern - this is influenced by the level of economic development and geography and (v) competing demands - in most countries residues are used for purposes other than fuel (as fertilizers, for example).

48. It is difficult to estimate the demand for residues in developing countries. First, not enough is known of the nature and patterns of energy demand in many countries. Secondly, the bulk of the energy sources are considered "non-commercial"; hence data on them are not readily available. There are also major differences in the level of residue use from region to region.

49. It is possible, however, to identify the activities in each sector of the economy for which residues could be used as an energy source. For example, (i) fuel in rural industries for heating, cooking, wood or metal working, forging, smelting, brick-making, mineral-processing and agro-industry; (ii) fuel in agriculture for planting, pumping, harvesting, drying, parboiling and milling; (iii) fuel in the household sector. For those countries surveyed, the supply of agricultural residues has been found plentiful. Some residues can be converted to appropriate forms, and thus facilitate demand and supply matching. There are, however, constraints to the development and widespread use of agricultural wastes including (i) cost of conversion and end-use technology; (ii) non-availability of suitable technologies; (iii) lack of information on the resource base and socio-cultural inhibitions of the population with regard to some applications; (iv) lack of convenient collection techniques and excessive transportation distances to processing points.

50. A wide range of technologies for particular end-uses in conversion processes are available. The main problems relate to the availability of skills to operate and maintain the hardware and the cost of technology.

51. It would be useful to develop a uniform methodology for assessing the supply potential of agricultural wastes, taking into consideration the issue of accessibility of non-farm residues. In this context, it must be borne in mind that the expected level of accuracy of data depends on the target group envisaged - including policy makers, planners or field project officers.

52. Economic feasibility studies of the various options for the conversion or utilization of agricultural residues are necessary. Technologies best suited for application of agricultural residues should be promoted, through demonstration, provision of credit facilities and extension services. Furthermore, local capabilities for the manufacture of suitable technologies should be promoted and developed.

V. SOCIAL, CULTURAL AND POLITICAL ASPECTS

53. The lack of progress in the development and utilization of new and renewable sources of energy in rural areas may in large part be attributed to inadequate knowledge of or attention being given to the socio-economic condition of rural people and their political and social organizations and structures.

54. The supply of energy can be a powerful mechanism for change in rural areas; it can make human energy more efficient, thus helping to alleviate poverty. To realize this goal through supplying energy, one must be fully aware of the social, economic and political realities of the lives of rural people. Energy technologies

should not reinforce the gap between the haves and the have nots, either within the household or between socio-economic groups. It is most important to recognize the political context in which a change in energy use is to be introduced and how that change can be affected by national, local and household decisions.

55. Some of the improved stove programmes provide examples of failures resulting from lack of attention to the above-mentioned issues. A woman's time is of the utmost value. Women spend more time in agricultural and household activities than do men. Fuelwood collection, cooking and food processing can take an average of four hours a day. If the "improved" stove demands more wood chopping or is not appropriate for the type of cooking required, if it does not save her time, a woman will not deem the stove more efficient or a value added to her life. Any new energy source and any technology used has to fulfil an obvious need as perceived by the user, either in time saving, reduction of a health hazard or improved sanitary conditions.

56. Ignorance of the dynamics of the power structures in the household, area or country can often result in rural energy schemes failing from the start. For example, afforestation on common land, although well-intentioned, has sometimes only eliminated a safety net for the very poor who gather wood there. The same holds true for some schemes for the utilization of agricultural residues. In some cases also, programmes launched to create income-generating activities for women have resulted in women doing all the additional work but not gaining control of the resulting income. Energy supply for micro enterprises or cottage industries such as milling, beer-making, food-making, flower and vegetable cultivation is important and benefits women, especially if accompanied by policies for supporting transportation infrastructures to gain access to local markets and providing some credit mechanism targeted for women. More information on the functioning of existing micro enterprises is needed.

57. Men may perceive themselves as losers in such development efforts, at least at the beginning. There is, however, a general feeling that, despite initial resistance, when the benefits become obvious, the men in the community whole-heartedly support energy programmes targeted at women. This may be illustrated by an example from a project in West Asia to introduce biogas digesters into a very poor village. Improved sanitary conditions inside and outside the home were perceived by the men as an added benefit. In many countries the involvement and approval of the men may be needed if projects targeted at women are to succeed.

58. The influence of socio-economic level on the type of energy used is in some cases not so great as assumed in the past. For example, in a community in India, cow dung and fuelwood were used for cooking by all levels of society because this was considered more economical than the switch to more conventional fuels and modern technologies. An increase in surplus cash income for rural populations is, however, a necessary (but not sufficient) condition for the switch to more conventional fuels and modern technologies.

VI. ENVIRONMENTAL ASPECTS

59. Environmental aspects of the supply and use of rural energy can be looked at from two points of view; the first relates to the specific effects on the local environment and the second to the intercountry and global dimensions. On the supply side, environmental concerns relate to deforestation caused in some cases by a rapidly growing population, which needs to add to agricultural output through the clearing of additional land and to provide more fuelwood. Generalizations are not possible because available studies and research deal with specific areas and time periods and quite often lead to inconclusive or contradictory results. Consideration of the relevant environmental costs of conventional energy would generally promote the development of new and renewable sources.

60. Often neglected but requiring much closer attention are environmental effects on the lives of rural people, particularly in the household sector. Women as the main users of energy in the household are the main victims of health hazards such as smoke and unsanitary conditions. Biogas digesters are a promising example of an environmentally benign energy source for cooking; they can provide fertilizer for increased agricultural production, while reducing diseases caused by organic wastes.

61. Similarly, solar thermal collectors can supply energy in the form of heat or mechanical power while windmills and photovoltaic systems can supply electricity to rural areas. The quality of life in these areas could be improved, household drudgery, particularly for women, could be reduced and higher incomes could be generated through agro-industries and related activities.

62. From a global perspective, there is an interest in promoting more environmentally benign energy technologies in the developing countries, in particular in areas having large rural populations. But these environmental concerns should not detract from efforts to increase energy supplies in rural areas. Economic and social advances in rural areas perhaps lead to more efficient utilization of energy resources, and a shift from traditional to conventional and renewable sources of energy - or rather to a fuel mix that is relatively benign for the environment.

VII. ENERGY INVESTMENTS AND PRICING

63. Investments in programmes and projects in new and renewable sources of energy had been scaled down even before the collapse in oil prices in the mid-1980s for a variety of reasons, including the apparent high cost of such investments, unduly high expectations of major technological breakthroughs and inadequate commitment on the part of Governments for the development of new and renewable sources of energy.

64. The economic condition of developing countries, especially in Africa and Latin America, deteriorated during the 1980s owing to a variety of factors, including foreign indebtedness and adverse terms of trade. Economic readjustment in many developing countries resulted in lower investments in social programmes with particularly adverse consequences for the poor, especially in rural areas.

65. Lower energy prices led to much lower investments by transnational oil corporations, particularly in energy-deficient developing countries at a time when their energy consumption had resumed an upward path. A resumption of economic growth during the 1990s would result in considerable increases in energy consumption in those countries. The prospect of higher oil prices during the decade would once again result in serious problems for the energy-deficient developing countries, particularly in rural areas, with additional pressure on limited biomass resources, such as fuelwood.

66. Developing countries are expected to experience higher rates of economic growth, industrialization and urbanization. Energy demand in those countries is expected to grow accordingly, with energy conservation and efficiency offering the prospect of partial relief only. This is especially the case with electricity, which requires heavy investments at a time when both multilateral and bilateral financial sources are scaling down their activities.

67. Although as a matter of policy the World Bank continues to support efforts to develop applications of new and renewable sources of energy, its overall involvement, except in the case of fuelwood, has tapered off. This trend mirrors similar policies in other international financial agencies and bilateral co-operation activities in this area.

68. In the early 1980s, when interest in new and renewable sources of energy was high, developed countries devoted much research and development to these resources as part of their national effort and in relation to bilateral and multilateral assistance programmes.

69. Similarly, a number of private corporations also initiated research and development programmes. Since then, both public and private research and development activities have been scaled down. In many developing countries, research and development programmes, including the establishment of several institutes and research centres, have been undertaken with national financing and/or outside assistance. In most cases, however, projects have not moved beyond the demonstration stage.

70. There have been some notable investments and development in the field of new and renewable sources of energy - for example, in the rural areas of China and India. In China, government policy that encouraged investment in certain technologies in rural areas has led to widespread application of such technologies, which have played a significant role in helping meet the energy needs of rural areas.

71. In India, a total of 1.2 million biogas plants have been set up, with an estimated saving of 4.24 million tons of firewood equivalent, valued at $US 100 million a year. In addition, the production of 20.4 million tons of enriched manure a year is valued at more than $US 100 million. As a result, total investment in biogas plants is paid back over a period of 2 1/2 years. Similarly, over 6.3 million improved stoves have resulted in a saving of 4 million tons of firewood equivalent a year, with a monetary benefit of $US 95 million.

72. New environmental concerns, especially climate warming and the contribution of carbon dioxide from fossil fuels, have led to increased interest in the energy situation and prospects of developing countries, including rural areas. This interest is related to deforestation trends and their impact on both the local and the global environment. As a result, several developed countries have expressed interest in increasing their financial assistance for energy development in developing countries, including new and renewable sources of energy in rural areas.

73. A major problem continues to be the urban bias of both national and outside investment sources. This issue is related to political development efforts in rural areas of developing countries, which, with a few exceptions, have not yet led to equitable distribution of income and economic development efforts in those areas. In many cases, conventional energy sources in developed and developing countries have been subsidized for long periods of time. The expansion of rural energy supplies would also require subsidies especially with regard to new energy technologies. However, as an overall policy, end-users would eventually have to finance investments through competitive prices. In some cases, a nominal price at least, would have to be charged as an incentive to users to maintain energy facilities properly.

74. A number of new examples of financing facilities such as revolving funds and energy banking have been introduced to enhance energy investment in rural areas. In India, the application of the concept of energy banking could facilitate the introduction of electricity from wind and photovoltaic farms into existing electricity systems.

75. Investments for the supply and use of rural energy are of course influenced by the nature of the facilities, which are isolated and small, and by the socio-economic conditions of the country concerned, including organizational structures in rural areas such as co-operatives and individual ownership of land. The private sector has sometimes participated successfully in energy investments for rural areas.

VIII. PROPOSALS FOR FURTHER ACTION

76. For each theme discussed, the following proposals for action were agreed upon:

(a) Energy Supply and Demand

(i) National and regional assessments of available resources of new and renewable energy should be encouraged; they should be carried out using available data, information and knowledge;

(ii) Development should continue with the aim of providing improved, common and standardized methodologies for surveys on resources, supplies and use of new and renewable sources of energy in rural areas, with emphasis on evaluation of their accuracy in order to provide a better base for planning and the formulation of policies;

(iii) Multilateral and bilateral assistance agencies should expand their programmes to assist developing countries in carrying out surveys of energy resources and demand and supply prospects with particular reference to rural areas;

(iv) Inventories should be made of existing natural forests. There is a need to develop management systems and implementation programmes for natural and artificially regenerated forests for sustained yield with the involvement of the local population, and to assess the possible production of these forests; to this end efforts should be made to integrate woody vegetation into farming for the stabilization of farming systems and for the production of wood and other forest products, parallel with agricultural production;

(v) Evaluations should be carried out on the availability, distribution and techno-economic feasibility of expanded and more efficient use of agricultural residues for rural energy supplies and related applications, bearing in mind competition with other uses of fertilizers.

(b) Technological options

(i) Ways and means should be examined for the transfer to developing countries of technologies developed largely in developed countries and for their application in order to promote national self-reliance and long-term capabilities. Such technologies include:

a. Small hydro plants for shaft power and electricity generation;

b. Wind pumps for water lifting;

c. Biogas plants for cooking and lighting;

d. Photovoltaic units for lighting and refrigeration;

e. Solar thermal energy;

f. Improved stoves;

(ii) Research and development centres on new and renewable sources of energy in developing countries should be strengthened and further action should be taken by the United Nations Committee on the Development and Utilization of New and Renewable Sources of Energy to promote the networking of centres on priority technologies at the regional and subregional levels;

(iii) Local manufacturing industries should be promoted to ensure increased utilization of new and renewable energy resources and, in the process, develop local know-how;

(iv) National and regional organizations should assess the availability and distribution of manufacturing industries, resources and technological capabilities for the increased application of such technologies in rural areas. Relevant manufacturing standards and specifications should be developed;

(c) Social, cultural and political aspects

(i) Social, cultural and political aspects of energy development and use with particular reference to the role of women in integrated rural development in developing countries deserve much closer attention and analysis;

(ii) Efforts should be made to channel energy to household activities that generate income;

(iii) An evaluation of the impact of energy in alleviating household and rural drudgery should be undertaken;

(iv) Guidelines should be developed for updating local data through rapid rural appraisals;

(d) Environmental aspects

(i) Assessment should be made of the environmental impact of new and renewable sources of energy, including local, national and global effects with projections incorporating scenarios of their expanded development and utilization;

(ii) When the environmental impact of energy in rural areas is evaluated, note should be taken of the competition and conflict between alternative uses of land; for example, for developing urban conglomerates, for roads and for forestry or agriculture including the competing uses of biomass for industries;

(iii) Environmental costs should be incorporated in the assessment of energy project proposals;

(e) Energy investments and pricing

(i) Information should be exchanged on financial and price incentives and their effects on investments for the development and utilization of new and renewable sources of energy, including research and development, with particular reference to rural areas. Factors having a bearing on national and outside sources of financing in this field should be included;

(ii) New and renewable sources of energy should be incorporated into existing investment and pricing policies and schemes for conventional commercial sources of energy in order to provide them with an opportunity for fair competition;

(iii) When investment analyses for new and renewable sources of energy projects and programmes are undertaken, it must be realized that the development stage is four times as expensive as the scientific discovery stage. More resources should thus be allocated to the development stage;

(iv) Countries should encourage the development of credit and marketing systems specially designed to promote the use of promising technologies;

(v) A balanced system for taxation and customs policies should be developed to correct the wide variations that currently exist for different imported items in the form of finished goods; for example, diesel generators and material for solar water heaters.

77. The following overall suggestions were agreed upon:

(a) Strategies, plans and policies in developing countries should incorporate new and renewable sources of energy as an integral part of overall energy in the context of rural development, which in turn should be viewed as part of national development. At the same time, rural energy policies and plans should form part of national energy plans which should in turn be viewed as an integral part of national development strategies;

(b) Action should be taken to promote the establishment or strengthening of extension programmes for education, generation of awareness, popularization and dissemination of energy technologies in rural areas;

(c) Action should be taken to promote the exchange and enhance the flow of information on energy technologies and related matters, considering the interdisciplinary nature of energy development. In particular, national, regional and international information networks and new and renewable sources of energy for rural areas should be strengthened. In this context, those active in the field are urged to publish or make available information on their experiences;

(d) More effort should be directed towards establishing or strengthening national institutions for policy formulation, planning and implementation of energy development strategies including those for rural areas. This should include training of personnel in various areas of expertise including assessment of energy demand and supply, development, adaptation and transfer as well as identification of appropriate and mature technologies for renewable sources of energy; and construction, installation, repair and maintenance of rural energy technologies. The training of trainers should be emphasized;

(e) Intended users of energy technologies in rural areas should actively participate in the planning, design and implementation of programmes and projects in order to enhance the prospects for success in the introduction and widespread application of such technologies;

(f) Bilateral, regional and international co-operation in new and renewable sources of energy should be promoted through exchange of information and transfer and adaptation of technologies.

Notes

a/ Report of the United Nations Conference on New and Renewable Sources of Energy, Nairobi, 10-21 August 1981 (United Nations publication, Sales No. E.81.I.24), chap. I, sect. A.

b/ Ibid., chap. I, sect. A, para. 26.

c/ Official Records of the General Assembly, Forty-third Session, Supplement No. 36 (A/43/36), annex, resolution 1 (IV).

d/ A list of the technical papers presented is available in the files of the United Nations Secretariat.

e/ See the report of the Secretary-General on the implementation of resolution 2 (III) of the Committee on the Development and Utilization of New and Renewable Sources of Energy at its third session (A/AC.218/15).

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Item 4 of the provisional agenda*

IMPLEMENTATION OF THE NAIROBI PROGRAMME OF ACTION FOR THE DEVELOPMENT AND UTILIZATION OF NEW AND RENEWABLE SOURCES ENERGY

Activities carried out by entities within the United Nations system concerning the contribution of new and renewable sources of energy to integrated rural development, direct solar-to-electricity energy conversion and the utilization of agricultural residues and urban wastes for energy production

Report of the Secretary-General

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* A/AC.218/1990/1.

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INTRODUCTION

1. At its fourth session, from 28 March to 8 April 1988, the Committee on the Development and Utilization of New and Renewable Sources of Energy requested the Secretary-General to prepare a report, for detailed consideration at its fifth session, on activities carried out by the entities within the United Nations system on the following themes: contribution of new and renewable sources of energy in integrated rural development; direct solar-to-electricity conversion and utilization of agricultural residues and urban wastes for energy production. 1/ The present report has been prepared in response to that request.

2. The United Nations Conference on New and Renewable Sources of Energy, held in August 1981, identified five broad policy areas for concerted action: (a) energy assessment and planning; (b) research, development and demonstration; (c) transfer, adaptation and application of mature technologies; (d) information flows; and (e) education and training. 2/ The Conference affirmed that within the above-mentioned broad policy areas, specific measures were needed. Some of the specific measures are source-specific, e.g., hydropower, biomass, wind and solar energy. During the preparatory process for the Conference, the status of new and renewable sources of energy and the prospects for their use were reviewed and specific activities at the national and international levels needed to realize their full potential were suggested. The Conference affirmed that many of the areas considered during the preparatory process were in a stage of scientific and technological evolution and that the findings related to the priorities and measures should be kept under review.

3. The Conference identified rural energy as one of the areas for priority action 3/ and recognized, in particular, that meeting rural energy development programmes within the context of integrated rural develpment programmes was of great urgency, especially for developing countries. In this context, the Conference recommended that the international community, and the United Nations system, in particular, should develop and implement programmes and projects in this and other areas for priority action.

4. The above priorities, as reflected in the Nairobi Programme of Action for the Development and Utilization of New and Renewable Sources of Energy, were endorsed by the General Assembly 4/ and the Committee during its subsequent sessions. At its first session, from 18 to 26 April 1983, the Committee recommended that the relevant organs, organizations and bodies within the United Nations system should prepare their detailed projects for immediate implementation on the basis of the framework provided in the report of the Administrative Committee on Co-ordination (ACC) on proposals for action-oriented plans and programmes for carrying out the Nairobi Programme of Action (A/AC.215/5) and taking into account, inter alia, that attention should be paid to the use of agricultural, industrial and urban wastes and by-products for energy production. 5/ It added that special attention should be paid to the preparation of programmes and projects for the improvement of the

availability and use of energy in rural areas so as to accelerate overall economic development of developing countries.

5. The paragraphs below reflect reported activities undertaken since 1988 by the United Nations system in regard to (a) contribution of new and renewable sources of energy to integrated rural development; (b) direct solar-to-electricity energy conversion; and (c) utilization of agricultural residues and urban wastes for energy production. Many of the activities highlighted below are carried out by individual entities within the United Nations sysem in co-operation with developing countries and are thus part of national programmes for economic development.

6. For a number of reported activities under (a) above, there were no clear-cut indications as to whether or not they fell under or were directly related to the contribution of new and renewable sources of energy to integrated rural development. In such instances, some element of selectivity was deemed inevitable in arriving at which programmes and projects to include in this section.

I. CONTRIBUTION OF NEW AND RENEWABLE SOURCES OF ENERGY TO INTEGRATED RURAL DEVELOPMENT

7. The Department of Technical Co-operation for Development is undertaking the investigation and testing of various types of new and renewable sources of energy equipment that should lead to the local manufacture of suitable designs in Mongolia. Emphasis has been placed on small wind generators for nomadic herdsmen, biogas digestors for cattle farms, and solar water heaters. The Department has been providing assistance to the programme for co-operation in the field of energy of the Economic Commission for Latin America and the Caribbean (ECLAC) and the Latin American Energy Organization (OLADE), with focus on energy planning, energy conservation, analysis of energy financing, studies of rural and marginal urban energy use and training in integrated energy planning.

8. The Economic Commission for Europe (ECE) undertook a feasibility study and prepared technical reports on the use of new and renewable sources of energy in agriculture, and is providing technical information on wood energy and the use of residues as an energy source. It has developed a data base on energy from wood.

9. The Economic and Social Commission for Asia and the Pacific (ESCAP) has been implementing a regional rural energy planning and management programme, which comprises four parts: (a) impact assessment of rational use of energy supplies in rural development; (b) rural energy planning and management interactions; (c) social and economic impact of rural electrification; and (d) study tour and evaluation of new and renewable sources of energy utilization for rural electrification. Reports have been prepared and results from country studies disseminated. Training and research programmes have been undertaken in energy management. ESCAP provided assistance in identifying promising technologies for utilizing biomass, including biogas, and in strengthening the capability of national institutions in rural energy planning techniques.

10. ESCAP is also implementing phase I of a project on photovoltaic systems for rural areas, which involves regional co-operation in research, development and demonstration on photovoltaic systems in Indonesia and Pakistan, and the provision of training and information on the status of the development and application of photovoltaic technology. It has undertaken training and establishing pilot projects in photovoltaic electrification for remote communities in Pakistan. It has organized seminars in China and Fiji on the social and economic impact of rural electrification. ESCAP has prepared a technical publication on rural energy and integrated planning in the Asian and Pacific region. It has published a report on cooking stove technology and problems associated with its dissemination.

11. The Economic and Social Commission for Western Asia (ESCWA) made a comprehensive assessment of technical, economic and social aspects associated with the introduction of biogas technology in rural areas of Syria. It organized a seminar on biogas technology for application to rural areas in selected countries in the region. ESCWA published a report reviewing the main activities in the region in the field of new and renewable sources of energy, in particular, solar-industrial demonstrations, electricity generation in remote areas, the development of mini-hydro and the promotion of its use, particularly in rural and remote areas of the region.

12. The Food and Agriculture Organization of the United Nations (FAO) continued afforestation programmes and the establishment of woodlots aimed at obtaining adequate wood resources for energy in remote areas. It executed an inter-country programme promoting rural development through a better mix of conventional and new and renewable sources of energy. In Nepal, FAO has been involved in a watershed and fuelwood plantation project. It has also provided technical assistance to Malawi in the use of draught animal power.

13. The International Bank for Reconstruction and Development (IBRD) is providing technical and financial assistance to India that would result in the improvement of infrastructure in the rural areas and provide irrigation water. It is also funding a project in India for the establishment of fuelwood plantations. The IBRD is providing assistance to Sri Lanka in agricultural development and the establishment of fuelwood plantations; to Mauritius in the use of bagasse for electricity generation; and to Nigeria in improving the supply of fuelwood. It assisted Malawi in the execution of a wood-energy conservation project.

14. The International Development Association (IDA) is providing assistance to China in the establishment of fuelwood plantations and to Uganda in the management of forests. In Nepal, it is continuing with the second phase of a rural development project that includes the expansion of forestry plantations.

15. The United Nations Industrial Organization (UNIDO) assisted Paraguay in the development of appropriate renewable sources of energy for use in rural areas. It provided assistance to Vanuatu in investigating small-scale charcoal production by rural women. UNIDO is assisting China in the establishment of an industrial biogas technology demonstration plant and experimental stations and has been providing training, as appropriate. It promoted the design and manufacture of small-scale hydropower equipment for rural development.

16. The United Nations Development Programme (UNDP) provided funding for an integrated programme in Indonesia aimed at developing and disseminating rural technologies based on new and renewable sources of energy through technology transfer. It also funded (a) the promotion, manufacture and use of improved wood stoves in the Gambia; (b) a study on forestry conservation in Ethiopia; and (c) the dissemination of information on improved wood stoves in Malawi. It assisted the Sudan in the production of fuel briquettes and improved cooking stoves for households and is currently assisting Mauritius in the reduction of fuelwood consumption and in the distribution of cooking stoves in urban areas.

17. The United Nations Environment Programme (UNEP) provided training services to Bolivia and Brazil in the maintenance and rational use of community forests and in the use of fuel-saving stoves. In Senegal, it co-operated with the Agence Française pour la Matrise de l'Energie in establishing a rural energy centre, charged inter alia, with demonstrating the feasibility of generating electricity by selected new and renewable sources of energy.

II. DIRECT SOLAR-TO-ELECTRICITY ENERGY CONVERSION

18. The Department of Technical Co-operation for Development is providing assistance to China in the development of photovoltaic systems in the western part of the country. In addition, a United Nations symposium on solar energy applications, including photovoltaics, was convened in China. The Department is also assisting Mongolia in the feasibility of producing solar cells in the country and Romania, in increasing the capacity of the new energy sources laboratory to enable it to undertake research, development and demonstration of more efficient photovoltaic systems and to develop hybrid photovoltaic/wind systems. In addition, the Department is providing technical assistance to Pakistan in demonstrating photovoltaic technologies for rural communities and to the Seychelles in establishing photovoltaic pilot units for telecommunications.

19. The Economic Commission for Africa (ECA) undertook two advisory missions to the Regional Centre for Solar Energy to provide assistance in technical, economic and managerial aspects of solar energy (including photovoltaic) development in the African region. The Economic Commission for Europe (ECE) has made studies on the current situation and future prospects for the use of new and renewable sources of energy, including photovoltaic systems in agriculture.

20. ESCAP developed and provided training courses in the region on photovoltaic systems and applications. It also provided advisory services and undertook studies on selected activities in new and renewable sources of energy, including photovoltaic systems. In Pakistan, it created training and pilot projects in photovoltaic systems for the electrification of local communities. It is planning a regional working group on rural energy, including new and renewable sources of energy and photovoltaic systems.

21. ESCWA undertook a study reviewing the present situation and future development of solar (including photovoltaic) and wind technologies in the region, while UNDP provided Malawi with locally manufactured water pumps. UNEP installed photovoltaic

generators in Senegal (in co-operation with the Agence Française pour la Matrise de l'Energie) as part of the establishment of a rural energy centre in the country. The United Nations Institute for Training and Research (UNITAR) organized a promotional workshop on photovoltaic systems to inform decision makers and system design engineers in the ECLAC region on the potential of such systems in rural areas and villages. Meanwhile, the World Meteorological Organization (WMO) has been providing assistance to southern European countries in improving the development and use of solar (including photovoltaic) technology and other new and renewable sources of energy.

III. UTILIZATION OF AGRICULTURAL RESIDUES AND URBAN WASTES FOR ENERGY PRODUCTION

22. FAO is providing assistance to China in integrating various technologies for producing alcohol from sweet sorghum stalks. It is providing assistance to the ESCAP region in technological development and diffusion of design, construction and operational data on a rice gasifier.

23. UNIDO provided advisory services to Haiti that included the question of the use of renewable sources of energy - mainly agricultural residues. UNIDO also undertook a project in Costa Rica that included investigating the possibilities of utilizing fuels from agricultural residues. It provided assistance to Thailand in energy management and the promotion of alcohol production from cassava. UNIDO also assisted the Philippines in promoting biogas technologies, including the utilization of energy crops, e.g., rice husks for gasification and direct combustion to serve the requirements of agro-industry in rural areas. It is assisting Ethiopia in the use of agricultural residues to produce energy for irrigation pumps in rural areas and gasifier engines powered by agricultural residues.

24. UNIDO provided assistance to the Sudan in the field, testing the production of charcoal from cotton stalks using small-scale decentralized methods, and is facilitating technical co-operation between Madagascar and China in the utilization of agricultural wastes to produce biogas for domestic consumption in rural areas. It assisted China in training personnel in the treatment of municipal and industrial wastes and the recycling of biomass wastes for energy production.

IV. CONCLUSIONS

25. Activities by entities within the United Nations system associated with the contribution of new and renewable sources of energy to integrated rural development were varied, covering such areas as studies, seminars, workshops or meetings, training, research, development and demonstration, information flows, energy assessment and planning, energy conservation, etc. Many of the activities involved providing technical or financial assistance to developing countries in any one or more of the above-mentioned areas.

26. There were relatively fewer activities on photovoltaic systems. These included technical and financial assistance in such areas as training, organization of seminars, workshops, symposia and establishment and demonstration of pilot projects.

27. The smaller number of activities in photovoltaics is an indication of the need for more effort in this area by entities within the United Nations system. It should be noted, however, that activities on photovoltaics are normally undertaken within the broader framework of programmes and projects in solar energy, which also include solar thermal applications, for which many technologies are mature and have been increasingly applied in the developing countries. It is expected that as photovoltaic systems become more competitive with other energy technologies, and acceptable in rural areas, increasing interest will be shown in them by the developing countries. This should be reflected in more requests for assistance to the United Nations system.

28. Even fewer programmes were reported in relation to the utilization of agricultural residues and urban wastes for energy production. This, however, is an area in which the United Nations system may wish to give more attention. For, as clearly indicated in document A/AC.218/1990/7, problems associated with the disposal of urban wastes, in particular, are considerable and will present a major burden to the developing countries in the future as their urban populations increase manyfold.

29. In the present report, account has not been taken of the activities carried out either nationally through local funding, through bilateral co-operation or arising from the activities of other multilateral organizations. These activities could be quite extensive compared with those undertaken by the United Nations system.

Notes

1/ Official Records of the General Assembly, Forty-third Session, Supplement No. 44 (A/43/44).

2/ See Report of the United Nations Conference on New and Renewable Sources of Energy, Nairobi, 10-21 August 1981 (United Nations publication, Sales No. E.81.I.24).

3/ Ibid.

4/ See General Assembly resolution 36/193 of 17 December 1981.

5/ Official Records of the General Assembly, Thirty-eighth Session, Supplement No. 44 (A/38/44).

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SUBSTANTIVE THEMES SELECTED FOR DETAILED DISCUSSION: DIRECT SOLAR-TO-ELECTRICAL ENERGY CONVERSION

Report of the Secretary-General

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INTRODUCTION

1. At its fourth session, from 28 March to 8 April 1988, the Committee on the Development and Utilization of New and Renewable Sources of Energy requested the Secretary-General to prepare a report on the current state of solar-to-electrical energy conversion for consideration by the Committee at its fifth session. 1/ The present report has been prepared in response to that request. After providing a brief review of photovoltaic apparatus (cells, modules and systems), it discusses the most successful and appropriate applications in use, and their costs, and considers future trends. Some conclusions and recommendations are presented. It draws heavily on a study commissioned by the Secretariat. 2/

I. BACKGROUND

2. Photovoltaic systems have been developed and refined over the past 15 years. The capital needed and the delivered electricity costs generated by them are high, compared with conventional, large-scale electricity production. However, given the increasing demand for electricity and the declining cost of the systems, due to improved technology and increased output, photovoltaic systems can be expected to play an increasingly important role in electricity generation in the future. This is particularly the case in the developing countries, where a small amount of electricity in rural areas can have a major impact on living conditions.

3. Photovoltaics have the following advantages:

(a) Since they convert sunlight to electricity entirely with solid-state electronic components, they are not dependent on fuels such as diesel and kerosene, which are often in short supply and expensive in rural areas. Moreover, they reduce reliance on imported fuels such as coal and oil;

(b) They produce no pollution and appear to have very limited environmental impact;

(c) They are modular in design and can be built up on a site in a flexible way, thus minimizing front-end financial risk and investment costs. Each system can be sited to meet the particular demand;

(d) They are durable and easy to maintain. Operation and routine maintenance are simple, and there is little degradation in performance over 15 years or more.

4. The principal types of photovoltaic cells are reviewed in table 1.

5. Photovoltaic cells can be interconnected in series and in parallel to achieve the desired operating voltage and current. The basic building block of a flat-plate solar array is the module in which the interconnected cells are encapsulated behind a transparent window to protect the cells from the weather and mechanical damage. One or more modules are then attached to a supporting structure to form a panel. A number of panels makes up an array field, which, along with the

Table 1. Properties of photovoltaic cells

Type of cell	Efficiency: Laboratory record (percentage)	Efficiency: Production record (percentage)	Advantages	Disadvantages
Single-cell (monocrystalline) silicon	23.1	10-13	Well established, tested technology Stable Relatively efficient	Uses much expensive material Much waste in slicing wafers Costly to manufacture Round cells cannot be spaced in modules efficiently
Polycrystalline silicon	18	10-12	Well established, tested technology Stable Relatively efficient Less expensive than single crystal Si Square cells for more efficient spacing	Uses much expensive material Much waste in slicing wafers Fairly costly to manufacture Slightly less efficient than single crystal
Gallium arsenide	29.2		Highest theoretical efficiency Can operate at high temperature (therefore useful for concentrations)	Very expensive Materials not abundant
Thin-film amorphous silicon	13.8	4.8	Very low material use Potential for highly automated and very rapid production Potential for very low cost	Sunlight induced degradation (Staebler-Wronski effect)
Thin-film cadmium telluride	12.3		Same as for amorphous silicon Does not degrade	Only in small-scale production for indoor applications
Thin-film copper indium diselenide	14.1		Same as for amorphous silicon Does not degrade	Not yet in production

/...

balance-of-system components, makes up the complete system. The array field may be sub-divided electrically into a number of sub-arrays working in parallel. Flat-plate arrays are normally fixed, with the modules supported by a structure that orientates them due south (in the northern hemisphere), inclined at or about the angle of latitude that maximizes the amount of solar radiation received on an annual basis. A steeper angle of inclination will enhance the output in winter, at the expense of some reduced output in summer.

6. In some circumstances, it is appropriate and cost-effective to mount the modules on a support structure that tracks the sun throughout the day. Given clear sky conditions, the output from the array tracked in that way is more uniform and can exceed that from a fixed array by at least 20 per cent; moreover, the extra output comes in the early morning and late afternoon, the times when demand for grid-supplied electricity is often highest. However, in view of the additional complications and the need for more skilled operation and maintenance, tracking collectors are generally not appropriate for remote sites.

7. A large number of concentrator photovoltaic devices have been developed, but the long-term prospects for them do not appear favourable, at least not for high-concentration systems with terrestrial applications. Except in special situations where the concentrator's higher efficiency and potential for providing thermal as well as electrical energy can be exploited to the full, flat-plate modules are preferable, owing to their simplicity and reliability. It should be noted that the optical components of the concentrating system (i.e., lenses or reflectors) have to be cleaned regularly, adding to the operational costs. However, until such time as very low-cost flat-plate systems are developed, low-concentration systems (e.g., double-mirror or Fresnel lens devices) will often be found to offer economic advantages for large installations at sites where the necessary skilled maintenance staff are available. A number of such systems have been built in recent years - for example, the 6.5 MWp central generating plant built by Arco Solar (United States), which uses double-mirror concentrating collectors. Work at Sandia Laboratories (United States) indicates that concentrator modules with efficiencies between 19 and 20 per cent could be in production in the next two or three years. 3/

II. APPLICATIONS OF PHOTOVOLTAIC SYSTEMS

8. Since photovoltaic modules provide an independent, reliable electrical power source at the point of use, they are particularly suited to remote or inaccessible locations. Suitable applications are outlined below.

(a) Rural electrification: lighting and power supplies for remote buildings and villages, street lighting, individual house systems, battery charging, mini grids;

(b) Water pumping and treatment systems: pumping for drinking water and irrigation, de-watering and drainage, ice production, saltwater desalinization systems, water purification;

(c) Health care systems: lighting in rural clinics, UHF transceivers between health centres, vaccine refrigeration, ice-pack freezing for vaccine carriers, sterilizers, blood storage refrigerators;

(d) Communications: radio repeaters, remote television and radio receivers, remote weather measuring, mobile radios, rural telephone kiosks, data acquisition and transmission (river levels, seismographs);

(e) Transport aids: road sign lighting, railway crossing and signals, hazard and warning lights, navigation buoys, fog horns, runway lights, terrain avoidance lights, road markers;

(f) Security systems: security lighting, remote alarm systems, electric fences;

(g) Corrosion protection systems: cathodic protection for steel structures, well-head protection, lock gate protection;

(h) Miscellaneous: ventilation systems, camper and recreational vehicles power, calculators, pumping and automated feeding systems on fish farms, solar water-heater circulation pumps, path lights, yacht/boat power, vehicle battery trickle chargers, earthquake monitoring systems, battery charging, fountains, emergency power for disaster relief.

A. Water pumps

9. More than 6,000 photovoltaic pumps are known to be operating throughout the world, and they are doing a good job of providing rural water and irrigation supplies. They are used to pump from boreholes, open wells, rivers and canals. Less common applications include de-watering, drainage pumping and water circulation for fish farms.

10. With technical problems now largely resolved, experience suggests that reports of poor performance are largely caused by incorrectly specified data on solar irradiation, water resources and water demand. Proper consideration must be given to those parameters and also to the well characteristics (yield and draw-down) if a system is to be operated correctly.

11. A comprehensive UNDP global project on photovoltaics in water pumping, executed by the World Bank, was completed in 1983. It included the testing of pumping systems in Egypt, Mali, the Philippines and Sudan. The result was a handbook 4/ which has been twice updated. 5/ The following accomplishments were reported:

(a) Mali provides a good example of solar pumping experience. Over the past 11 years more than 100 photovoltaic pumping systems have been installed, mainly under the auspices of Mali Aqua Viva, a charitable organization. A high degree of local involvement has been insisted upon, especially with construction work on water tanks, foundations, access etc. This has provided up to 25 per cent of the

initial cost of any one project and generated a high level of enthusiasm within the locality. Borehole centrifugal pumps have been the type most widely used in Mali, originally coupled to surface mounted direct current motors. More recent installations have changed to using pumps with submerged alternating current motor/pump sets because of their lower maintenance costs. Reliability of the equipment in the harsh Sahelian environment has been good, with the solar pumping systems operating for more than 95 per cent of the time. Most recent installations have operated faultlessly and effectively since being commissioned;

(b) India has the largest number of solar pumps of any one country. More than 500 systems have been installed for village water supplies. Good responses have been reported, along with wide user acceptance. The modules and systems have been indigenously designed and manufactured by Central Electronics Limited. The potential for the application of photovoltaic systems in India is so great that several other companies have started photovoltaic production.

12. In villages, there is a constant demand for water throughout the year, and there is need to store water for periods of low insolation. In Sahelian Africa the typical amount stored would be from three to five days of demand. In environments with rainy seasons, the reduced output of the solar pump during the rainy period can be offset by rain-water harvesting. The majority of solar pumping systems installed, to date, are for village water supply or livestock watering.

13. A solar irrigation system needs to take account of the fact that demand for irrigation water will vary throughout the year. Peak demand during the irrigation seasons is often more than twice the average demand. This means that solar pumps for irrigation are under-utilized most of the year. Attention should be paid to the system of water distribution and application to the crops. The system should minimize water losses, without imposing significant additional head on the pumping system, and be of low cost. Solar pumps are available to pump from anywhere in the range of 1.5 m to 200 m head and with outputs of up to 250 m^3/day.

14. Solar pumping technology continues to improve. In the early 1980s the typical efficiency of solar energy compared to hydraulic (pumped water) energy was about 2 per cent, with the photovoltaic array being 6-8 per cent efficient and the motor pumpset typically 25 per cent efficient. Today, an efficient solar pump has an average daily solar energy to hydraulic efficiency of more than 4 per cent. Photovoltaic modules of the monocrystalline type now have efficiencies of over 12 per cent, and more efficient motor and pumpsets are available. A good sub-system (that is, the motor, pump and any power conditioning) should have an average daily energy throughput efficiency of 30-40 per cent. A photovoltaic system for pumping 25 m^3/day through a 20 m head requires a solar array of approximately 800 Wp in the Sahelian regions. Such a pump would cost approximately $6,000 FOB. Other costs are shown in table 2.

15. A range of prices is to be expected, since the total system comprises the cost of modules, pump, motor, pipework, wiring, control system, array support structure and packaging. Systems with larger array sizes generally have a lower cost/Wp. The cost of the motor pumpsets varies according to application and duties: a low-lift suction pump may cost less than $800, whereas a submersible borehole pumpset costs $1,500 or more.

Table 2. Specifications for photovoltaic pumping systems

Motor pump/configuration	Output (m^3/day) at 5kWhm/m^3/day insolation	Head (m)	Solar array (Wp)	System price ($US FOB)
Submerged borehole	40	20	1 200	7 000-8 000
motor pump	25	20	800	6 000-7 000
Surface motor/submerged pump	60	7	840	5 000-6 000
Reciprocating positive displacement pump	6	100	1 200	7 500-9 000
Floating motor/pumpset	100	3	530	4 000
	10	3	85	2 000
Surface suction pump	40	4	350	3 000

B. Vaccine refrigeration

16. All vaccines must be kept within a limited temperature range throughout transportation and storage. The provision of vaccine refrigeration - known as the vaccine "cold chain" - is a major logistical undertaking in areas where electricity supplies are non-existent or erratic. The performance of refrigerators fueled by kerosene and bottled gas is often inadequate, and diesel-powered systems frequently suffer fuel supply problems. Solar power can provide a more sustainable cold chain.

17. The World Health Organization (WHO) began looking at solar power for refrigerators in 1980 5/ and has since made major contributions through the publication of technician and user handbooks 6/ and by running training courses. 7/ An infrastructure guide is currently in preparation. 8/ The World Bank has recently commissioned a status report and will hold a briefing in early 1990. 9/ Major programmes to utilize solar refrigerators are under way in the following countries:

(a) Zaire. The Department of Public Health and Social Affairs, with the technical and financial assistance of the European Economic Community, is installing 100 photovoltaic refrigerators (and 750 lighting systems) in rural hospitals and health centres. The operation will equip roughly 400 health establishments spread out over more than 20 per cent of Zaire's territory. A Zairian firm designed and now produces the refrigerators, utilizing importer compressor and batteries. 10/ User reaction has been good, and the systems have been more reliable than kerosene refrigerators. In 1986, the World Health Organization undertook an evaluation of the installations. Their conclusions were very supportive;

(b) Mali. Over six years of trials have taken place in Mali leading to the conclusion by the Laboratoire de l'énergie solar that, with periodic maintenance checks, the rate of equipment failure is negligible;

(c) Sudan. Under co-operation programmes with agencies in the United States and the Federal Republic of Germany, solar refrigerators are being installed in many rural health centres;

(d) Indonesia. A programme to install 300 photovoltaic refrigerators, together with 2,000 conventional refrigerators, is currently under way, with World Bank funding.

Projects involving significant numbers of solar refrigerators are also now under way in Chad, Ghana, Kenya, Mozambique and Sudan.

18. Compared with kerosene or bottled gas, refrigerators fueled by photovoltaic systems have the following advantages:

(a) Improved vaccine storage facilities as a result of the elimination of fuel supply and fuel quality problems, greater mechanical reliability, and better refrigerator performance (and temperature control);

(b) Reduced running costs as a result of the elimination of kerosene fuel costs, including transportation costs; reduced vaccine losses; lower refrigerator maintenance costs; and reduced need for back-up refrigerators when there are fuel supply or repair problems;

(c) Cold chain management benefits due to longer equipment life (photovoltaic array, 15 years; battery, 5 years; refrigerator, 10 years); reduced logistical problems arising from non-availability of working refrigerators; and reduced logistical problems arising from lower vaccine losses.

19. The disadvantages of solar refrigerators are as follows:

(a) The repair or replacement of a main component, such as the compressor control unit, requires skilled technicians;

(b) Since solar systems are site-specific, more time is needed for planning and setting them up;

(c) User training demands are high since overloading a solar refrigerator can cause it to become too warm.

20. A true comparison of solar refrigerators and comparable kerosene and gas-fueled refrigerators can only be made through a life-cycle cost analysis. A solar photovoltaic refrigerator is likely to cost $3,000-$4,000 and will cost more to install than a kerosene unit. A kerosene refrigerator will cost only $600-$800 but will use 0.5-1.0 litres of fuel per day, require frequent maintenance and have a shorter life. In general, life-cycle costs are approximately the same for solar and kerosene refrigerators, but because of their greater reliability (and the

resultant savings in spoiled vaccine that doesn't need to be replaced) solar refrigerators are the preferred option. Table 3 shows the relative costs of utilizing the two types of refrigerator in a health centre in Pakistan, serving a population of 12,000 with a crude birth rate of 4.5 per cent. It can be seen that a photovoltaic refrigerator is more economic. 11/

Table 3. Costs a/ of photovoltaic vs. kerosene refrigerators for vaccine storage in a Pakistani health centre b/

	Kerosene	Photovoltaic
Array (125 Wp - 15 yr. life)	-	13 047
Battery (2,400 Wh - 5 yr. life)	-	5 107
Refrigerator	10 400	22 490
Installation	2 880	7 219
Total, cost of installed refrigerator	13 280	47 864
Annual maintenance costs	1 400	479
Annual fuel costs (3.08 Rs/litre)	675	-
Annualized refrigerator life-cycle cost	5 579	8 894
Refrigerator reliability/availability	60%	97%
Doses of potent vaccine available	3 600	5 820
Programme cost per outlet	21 300	21 300
Annualized refrigerator life-cycle cost per dose of potent vaccine	1.55	1.53
Programme cost per dose of potent vaccine	5.92	3.66
Total cost per effective dose	7.47	5.19

a/ Measured in rupees.

b/ 6,000 doses/year required.

21. Photovoltaic refrigerators operate on the same principle as normal compression refrigerators, but the compressors and motors use low voltage (12 or 24 V) direct current rather than main voltage alternating current. A photovoltaic refrigerator will have higher levels of insulation around the storage compartments to maximize energy efficiency, a battery bank for electricity storage, a battery charge controller and a compressor, which converts the power from the battery to a form required by the compressor motor. Most refrigerators include a freezer compartment for ice pack freezing. Some systems have separate units to provide solely for

refrigeration or freezing. Storage capacity ranges between 10 and 200 litres of vaccine, with ice production rates of up to 5 kg per 24 hours.

22. Lead acid batteries are most commonly used, but long-life, deep-cycle batteries are preferred. A capacity to run the refrigerator for five days without sun is recommended. The charge regulator maintains the power supply within the current and voltage range tolerated by the refrigerator and prevents overcharge of the battery. Some models include an audible alarm or warning light to signal when the battery voltage becomes low. Lightning surge protection must be provided for tropical areas.

23. Vaccine refrigerators are required to maintain vaccine between +0° C and +8° C at all times. In addition, there is normally a requirement for a separate freezer compartment to freeze ice packs used for transporting vaccines in cold boxes. The performance of a refrigerator or freezer is dependent on the ambient temperature; therefore, specifications are usually defined at 32° C and/or 43° C. The following criteria are used to assess performance:

(a) Internal temperature distribution and variation within the permissible range of from +0° C to +8° C;

(b) The rate of icepack freezing in kilograms per 24 hours;

(c) Holdover time during loss of power - i.e., the length of time that the internal temperature of the refrigerator remains below 8° C when the power supply has been disconnected.

24. For system sizing, the energy consumption of a photovoltaic refrigerator in kilowatt hours over a 24-hour period must be known. For a 100-litre refrigerator without an ice-pack freezing capacity and operating at an ambient temperature of +32° C, the energy consumption is typically 300-500 Whr. At an ambient temperature of +43° C, with a freezing capacity of 2 kg of ice packs per 24 hours, the energy consumption of the same refrigerator would rise to about 600-1,200 Whr over 24 hours. Overloading a solar refrigerator increases energy consumption considerably.

25. A good vaccine refrigerator should be able to maintain correct internal temperatures for at least 10 hours in the event of being disconnected from the battery and solar array. WHO publishes data on approved photovoltaic refrigerators. 12/

C. Lighting

26. Photovoltaic systems for lighting should be considered wherever kerosene fuel supplies are erratic or expensive; good quality lighting is required (e.g., in schools and home industries such as needlework); and solar irradiation levels are moderate to high (>3 kWh/m/^{2}/day). They are suitable for lighting domestic or community buildings (homes, schools, community centres, mosques, churches); street, area or security lighting (car-parks, industrial areas, warehouses); portable light units; and specialized commercial lighting, such as terrain avoidance lighting for aircraft and other navigational aids.

27. Where mains electricity does not exist or is impractical, lighting is provided by kerosene lamps; kerosene hurricane lamps; diesel generators that power electric lamps, or automotive batteries that power electric lamps (periodically taken to towns for recharging). The relative merits of providing electric light by diesel generators, batteries and photovoltaics are given in table 4.

28. Kerosene lamps and candles have the obvious drawback of producing only a low light output and being a fire hazard. Although they have the lowest purchase price, they are expensive to run and inefficient. Even though individual photovoltaic lamps, compared to kerosene lamps, may be more expensive to buy initially, in general they are cost-effective on a life-cycle cost basis and provide light of better quality. The relative economics of photovoltaic versus kerosene lighting are shown in table 5.

29. The major difference between photovoltaic and other electric lighting systems is that direct current is produced; thus, the use of direct current lights is preferred. It is possible to use light with alternating current, however, by incorporating an inverter into the system, but the procedure will result in significant electrical losses. Hence, a larger array will be needed.

Table 4. Comparison of power sources for electric lighting

System	Advantages	Disadvantages
Diesel generators	Operating and maintenance experience is widespread Moderate capital cost Easy to install Can be a combined power supply for additional uses	Creates noise and air pollution Requires a reliable fuel supply High running costs High maintenance costs Low operating efficiency
Automotive battery recharging	Low capital cost Easy to install Batteries locally available	Relies on transportation to charging stations High charging fees Short battery lifetimes
Photovoltaics	High reliability Low maintenance requirements Low running costs Suited to most locations Long life-expectancy for main components	Involves the introduction of a new and often poorly understood technology High capital costs Not physically robust; vulnerable to damage Specialized batteries not widely available

Table 5. Life-cycle cost comparison: kerosene and photovoltaic lighting systems

Kerosene		Photovoltaic	
Weekly fuel requirement		Weekly energy requirement	
Kerosene pressure lamp	2.8 litres	Fluorescent lamps 2 x 8 W	64 Wh
Hurricane lamp	1.2 litres	Battery charging efficiency is only 80 per cent; hence, requirement	80 Wh
Weekly energy costs			
Kerosene at $0.3/litre	$1.20	Average daily insolation	5 kWh/m^2
Annual total	$62.40	Required array size	18 Wp
Capital costs		Capital costs	
Pressure lamp	$20.00	PV array	$150.00
Hurricane lamp	$55.00	Battery (100 Ah x 12 v)	$140.00
		Fluorescent lights (2)	$34.00
		Voltage regulator	$50.00
Total	$75.00	Total	$374.00
Recurrent costs		Recurrent costs	
Present worth of fuel discounted at 10 per cent over 15 yrs = $62.40 x 7.61	$475.00	Battery b/	$141.00
		Tubes c/	$28.00
		Voltage regulator d/	$24.00
		Total	$193.00
Present worth of replacements a/	$95.00		
Total life-cycle costs (15 yrs) = $25 + $475 + $95	$595.00	Total life-cycle costs (15 yrs) = $374 + $193	$567.00
Annualized cost	$78.00	Annualized cost	$74.00

a/ Lamps are replaced every two years.

b/ Replace every five years.

c/ Replace every two years.

d/ Replace every eight years.

30. In terms of the number of installations, lighting makes the greatest use of photovoltaics, with tens of thousands of units installed world wide. User experiences have been excellent, with increasing demand for more systems in localities where a photovoltaic light has been installed. Specific examples of lighting experience include:

(a) Dominican Republic. Approximately 70 per cent of the rural population have no access to the utility grid. In 1984 a photovoltaic rural electrification project was set up, using seed money from the United States Agency for International Development to install lighting systems. The fees charged for the systems have financed the purchase of further equipment, so that the project is now self-financing, with more than 50 systems installed.

(b) Thailand. In many villages, lighting is obtained by charging automotive batteries in towns and then using them to run 12-volt lamps. With Japanese seed-funding, the Ministry of Rural Electrification has installed 500 Wp photovoltaic battery-charging stations. Due to savings on replacement batteries and transportation costs, a photovoltaic system will pay for itself in three years or less.

31. Many direct-current lights are now commercially produced, but the most efficient in terms of light output (lumens) per watt of power consumed are low-voltage fluorescent tubes. If they are not available, conversion of alternating-current tubes is possible by changing the alternating current starter and ballast components to produce a direct current version. 13/

D. Grid-connected systems

32. There has been much discussion of the possibility that photovoltaics will eventually become cheap enough to be economical for grid-connected applications. At present, with oil and coal prices low, that prospect seems remote, but in the long term it could change, particularly for countries rich in solar energy but low in conventional fuels and unwilling (or unable) to introduce nuclear technology. Many countries have made a strong political commitment to the use of renewable energy resources, and some have gone further by deciding not to build any new nuclear power plants (e.g., Sweden).

33. Grid-connected systems are simpler and less expensive than stand-alone systems, since they require little or no battery storage. The grid itself can serve as "storage", with the photovoltaic plant supplying power to or drawing power from the grid, depending on the load and solar irradiance. There are a number of grid-connected photovoltaic systems in the United States, and the generation of economical solar electricity for grid distribution remains the goal of the United States Department of Energy. It could be of great importance in the future.

III. COSTS

34. It is widely accepted that the major factor inhibiting the widespread use of photovoltaics is their high cost. However, over the past 15 years, the price of the modules and systems has been steadily falling in real terms.

35. Module prices for both forms of crystalline silicon are currently about $4/Wp (exclusive of delivery or taxes) for large orders. Bearing in mind that the cells account for about 60 per cent of the module price, some further price reductions, possibly down to about $2-$3/Wp, are foreseen through the introduction of cheaper silicon and larger, fully automated manufacturing plants. Much lower costs, even down to $1/Wp or less, are potentially attainable with thin film cells. In view of the efforts being made world wide to develop different thin-film technologies, it is probable that large-area thin film cells will become available by 1990, with much improved efficiency and stability, compared with current products at prices below $3/Wp.

36. Obviously it is impossible to be certain that cost and price reductions can be achieved. This is dependent on development of the market demand as well as the techn$logy. Two very recent proposals for significantly reduced costs (and prices) are worth further study.

37. The Chronar Corporation in the United States has built its "Eureka" plant 14/ which produces thin-film amorphous silicon modules. When in full production of 10 MWp per annum, it should yield modules at a cost of $1/Wp. This will require a scale-up of the thin-film deposition equipment to deposit the films over an area of at least 1 m^2 and to develop a processing line for them.

38. Suryovonics of India, which is a partner of Energy Conversion Devices of the United States, has proposed its "global concept for low-cost photovoltaics". 15/ A 3 MWp per annum plant is currently under construction in Hyderabad. The proposed programme is to expand the capacity to 200 MWp per annum. But this proposes a novel approach of large-scale production of cells followed by decentralized finishing of modules.

39. The process involves two stages. The cell type is a multijunction, multilayer of amorphous silicon. In the first stage of the process, the amorphous silicon layers are coated onto thin stainless steel in the form of a long roll. This "front-end process" produces what is called "coated web" - which is a roll of photovoltaic cells up to 0.5 m wide and up to 600 m long. The second stage of production, called the "back-end process", is to cut the coated web to appropriate size and shape and encapsulate it into photovoltaic modules. The "global concept" is to produce the coated web in a large plant (200 MWp per annum) and ship it to a number of finishing plants whose capacity would be required to meet local market demand, which could be from 200 kW to several MW per year. The main capital investment is in the front-end plant.

40. The claimed production costs for the coated web process are summarized in table 6. Investors for the venture are currenlty being sought. (Possible cost reductions and future scenarios are discussed further in section IV of this report.)

Table 6. Production costs claimed for Suryovonics photovoltaic modules

Cost	Capacity (MWp per year) 2	25	75-150
Capital (millions of dollars)	10	40	90
Coated web ($/Watt)	1.88	1.02	0.56
Module finishing ($/Watt)	2.0	1.50	0.94
Finished module ($/Watt)	3.88	2.52	1.50

41. The economic characteristics of photovoltaic systems are different from those of most small systems in that the initial outlay on purchasing the equipment (the capital cost) is high; there are no fuel costs; maintenance costs are generally low; reliability is high, so that replacement costs are low; and the output of a system depends on its location, so its economic viability has to be assessed for each case.

42. In undertaking an economic evaluation, the following parameters should be considered:

(a) The life-cycle costs, which are the sum of the costs and benefits of the system accrued over its lifetime, expressed in present day value;

(b) The payback period, which is the length of time it takes for the total cost to be "paid for" by the value of benefits gained from the system;

(c) The rate of return, which is the value of the benefits gained from the system compared to the initial investment made.

IV. FUTURE TRENDS

A. Major programmes and projects

43. Significant research, development and demonstration programmes have been undertaken internationally on photovoltaic technologies since the mid-1970s, by Governments, private organizations and intergovernmental organizations such as the European Economic Community (EEC). 16/ Although expenditure by the International Energy Agency (IEA) member countries has decreased since a peak of some $300 million per year in 1981/82, since 1982 photovoltaics have been the biggest programme among the renewable technologies within IEA as a whole. The decline in

expenditure since 1982 largely reflects the withdrawal of United States Government funding from the very large-scale demonstration plant programme of the late 1970s through the early 1980s. However, this has, to some degree, been compensated for by substantial increases in recent years in the national programmes of Japan and the Federal Republic of Germany. The national programmes of the United States, Japan and Germany, between them, account for some 85 per cent of IEA governmental expenditure.

44. There is also a substantial research, development and demonstration effort by private industry, on which published information is not readily available. It may be assumed, for example, that photovoltaic manufacturing companies in the United States, in particular, have filled some of the gaps in research, development and demonstration expenditure created by the Government's withdrawal. In addition, there will inevitably be spin-off benefits for photovoltaic technology from research, development and demonstration in related areas (notably the semi-conductor and micro-electronics industries).

45. It is possible to identify three main themes underlying both national and industrial research, velopment and demonstration programmes: enhancing cell efficiencies; reducing costs; and, for amorphous silicon cells, inhibiting the degradation process.

46. The United States programme on photovoltaics for utility-scale applications is the best documented. It has the clearly defined goal of achieving a performance level such that grid electricity can be generated economically.

47. The world's largest project in the developing countries is worth noting. It is being funded by EEC as a component of a regional programme to combat desertification in the Sahel and West Africa. Approximately $35 million has been allocated to the regional agency, Comité inter-états pour la lutte centre la secheresse dans le Sahel, for the procurement of photovoltaic pumping systems and related equipment for water and electricity supply in Burkina Faso, Cape Verde, Chad, Gambia, Guinea-Bissau, Mali, Mauritania, Niger and Senegal. The project will install approximately 1,350 photovoltaic pumping systems along with about 500 other photovoltaic systems (for lighting, battery-charging and refrigeration). The total installed capcity will be about 1.3 MWp. Tenders for the first systems are currently being evaluated, and installations should commence in 1990.

B. Technology and the world market

48. The photovoltaic market is best considered by application, as follows:

(a) Consumer products - watches, calculators, shavers, vents, portable radios, cassette players and garden, sport and leisure products powered by photovoltaic cells;

(b) Remote power applications (i.e., remote from a national electricity grid) - water-pumping, refrigeration, telecommunications, navigational aids, cathodic protection, area lighting, building power, village power etc.;

(c) Grid connected - photovoltaic systems interfaced with a national utility grid, which may be considered as either central power stations feeding the grid or distributed residential, commercial and institutional building systems reducing the grid demand and/or feeding the grid.

49. The breakdown of the 1988 photovoltaic market by application is shown in tables 7 and 8 by module origin and region of application, respectively. To date, the grid-connected market has yet to become significant. Photovoltaics for consumer products accounted for approximately one third of the 36 MWp of photovoltaics sold in 1988. The remote power market used approximately 60 per cent of photovoltaics produced in 1988, of which it is estimated that only one third was for the developing country market.

Table 7. Photovoltaic market, by module origin, 1988

(MWp)

Module origin	Consumer products	Grid connected	Remote application	Total
Europe	1.6	0.6	4.1	6.3
United States	0.8	1.5	9.0	11.3
Japan	9.2	0.6	3.2	13.0
Rest of the world	0.1	0.2	4.3	4.6
Total	11.7	2.9	20.6	35.2

Table 8. Photovoltaic market, by region of application, 1988

(MWp)

Region of application	Consumer products	Grid connected	Remote application	Total
Europe	3.0	0.8	3.7	7.5
United States	4.0	1.0	5.9	10.9
Asia	3.6	1.0	6.8	11.4
Africa	<0.1	-	1.1	1.2
Rest of the world	1.0	1.0	3.1	5.1
Total	11.7	3.8	20.6	36.1

50. It has been noted above that there has been a steadily growing market for photovoltaic modules, coupled with decreasing costs. There is obviously a link between cost/price and market size, but it is incorrect to expect that a reduction in price will lead directly to a larger market.

51. There have been many projections of future photovoltaic costs and markets. The United States National Photovoltaic Programme 1987-1991 17/ aims to support the photovoltaic industry to achieve its ultimate objective - that, in the early 1990s, utility-sized photovoltaic systems will be economically justified and will be built in some parts of the United States. Beyond the 1990s, research and development would further reduce prices such that after the year 2000 photovoltaics would make a significant contribution to the electricity supply. The United States view of the evolution of photovoltaic technology is set out in table 9.

52. IT Power Limited is also involved with making projections of future photovoltaic prices and markets. Recent work for the British Department of Energy 18/ has involved reviewing all the forecasts and taking into consideration an assessment of the economic applications of photovoltaics, such as replacing diesels for small stand-alone remote power; an assessment of the financing required to achieve the market prospects, compared to the levels of financing currently available; and the market history of the various applications and the possible reasons for past forecasts being inaccurate.

53. Figure I gives photovoltaic module price forecasts to the year 2025. The baseline case is considered to be very realistic, with the low case being optimistic. The world market, which might be achieved for the two scenarios, is shown in figures II and III.

Table 9. Evolution of photovoltaic technology and applications a/

Decade	Technological advances	Application
1950	Bell Lab discovery	
1960	Crystalline silicon	Space programme
1970	New thin-film materials	Terrestrial research and development begun
1980	Mix of crystalline silicon and amorphous silicon	Remote applications become viable
1990	Multijunction thin-film cells	Utility market penetration begins
2000	High-performance low-cost cells	Significant photovoltaic contribution by national utilities

a/ Predictions by the United States Department of Energy.

Figure I. Photovoltaic price forecast

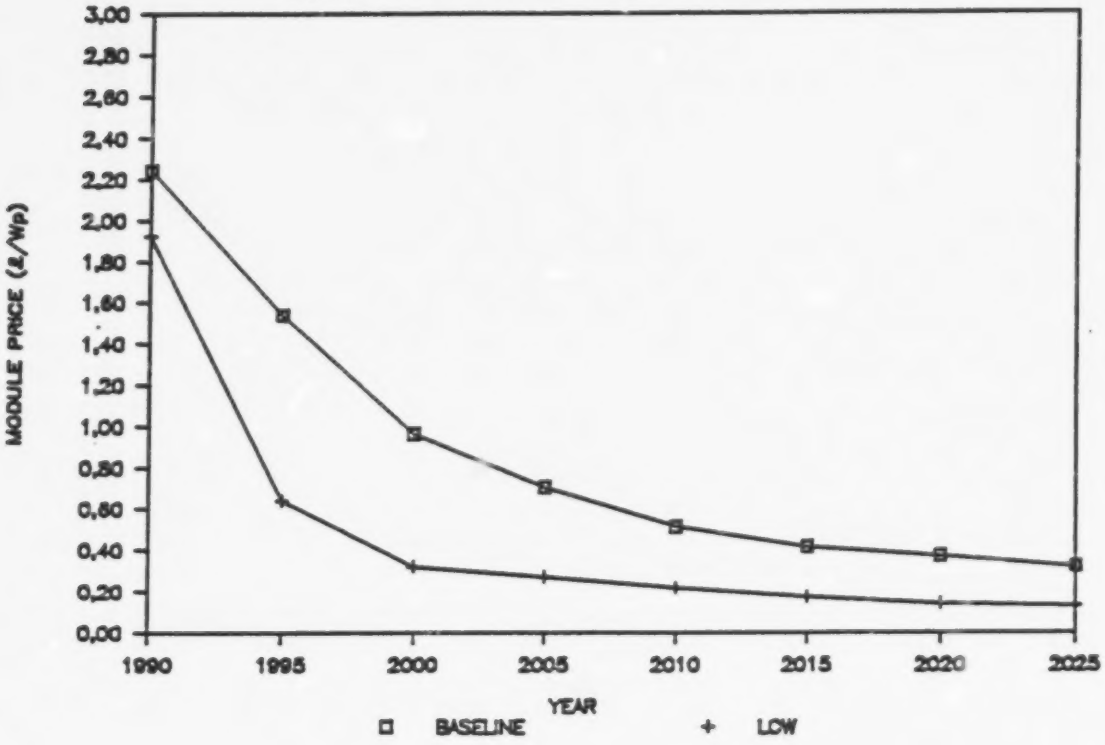

Figure II. Forecast for the global photovoltaic market: baseline case

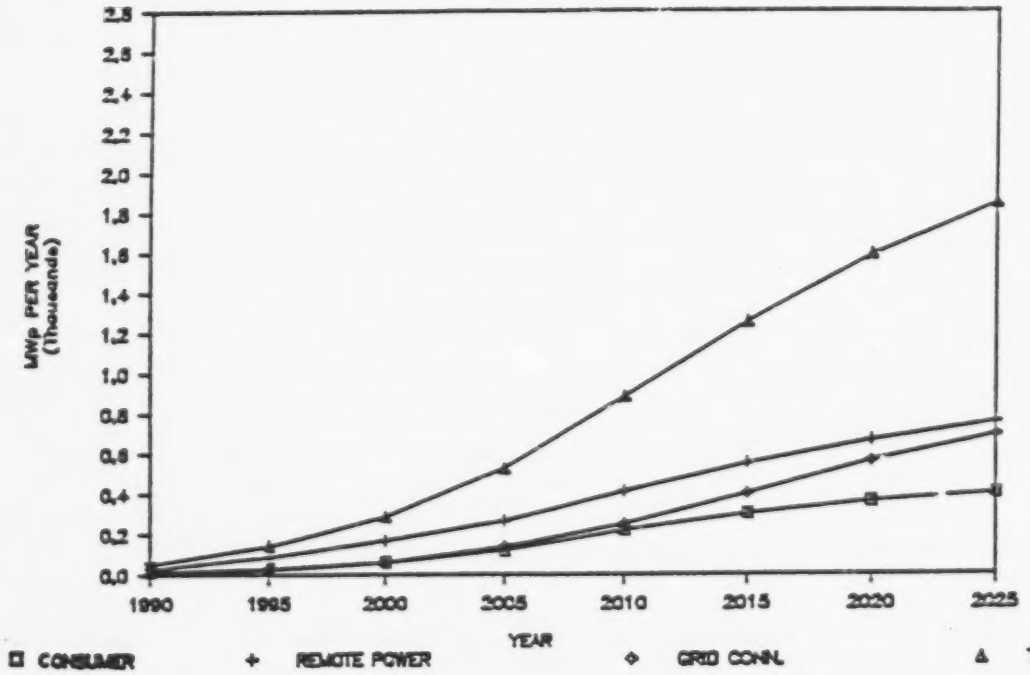

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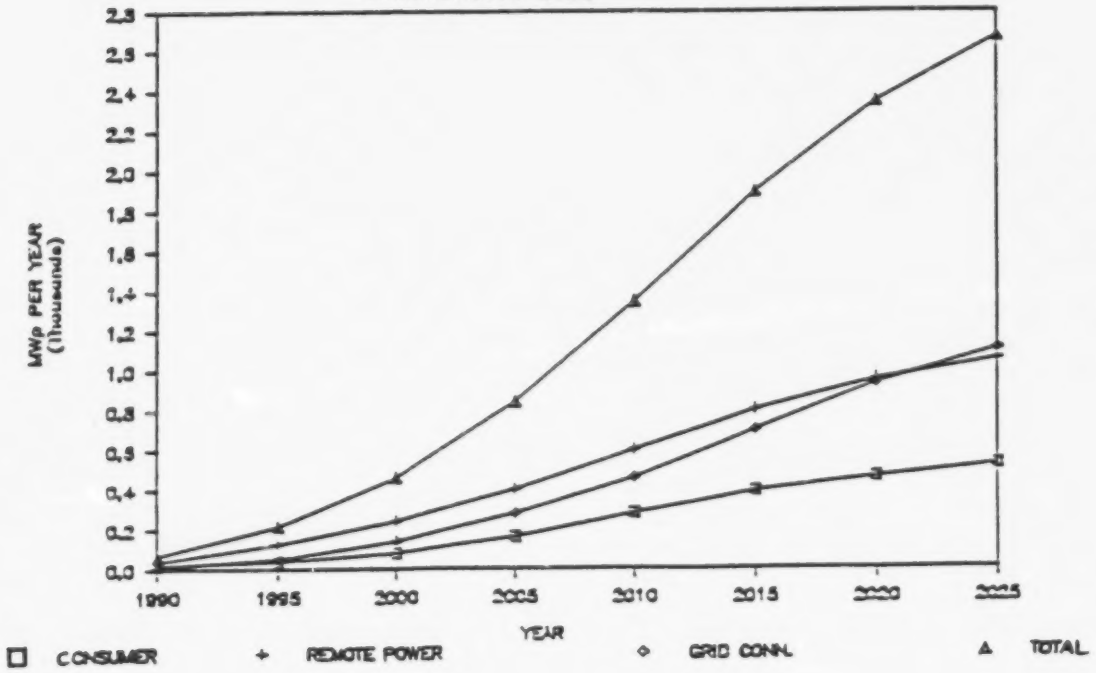
Figure III. Forecast for the global photovoltaic market: accelerated case



C. Manufacturing

54. Over the past 15 years a photovoltaic industry has emerged in practically every industrialized country and in many developing countries. As may be expected in a new area of technology, there have been a number of failures and disappointments as well as some notable successes. Many of the main photovoltaic manufacturers are subsidiaries of, or are majority-owned by, major oil companies, which see photovoltaics as a natural extension of their energy interest and as a field that may become very large in the future. In the United States, there are now some 10-15 companies well established in the manufacture and marketing of photovoltaic modules and systems.

55. In Europe, there are 8-10 photovoltaic manufacturers with annual production of at least 100 kWp. There are also smaller organizations more concerned with marketing systems using bought-in components. In Japan, at least six companies are active in photovoltaics, including several of the main manufacturers of electrical and electronic goods.

56. A number of developing countries are developing their own photovoltaic industries - notably Brazil, China and India. Locally manufactured photovoltaic modules are not significantly cheaper than similar products made in industrialized countries, but because foreign products are usually subject to import taxes, local manufacturers are protected and are thus able to secure the local market, supplying photovoltaic systems for demonstration projects and professional applications such as telecommunications.

57. In India there are two well established manufacturers, and production capacity exceeds 3 MWp per annum, with output around 2 MWp. Approximately 3,000 villages have photovoltaic systems installed (or due to be installed) mainly through government-financed demonstration projects. A very large new production facility is being built, and an experimental production line for amorphous silicon is also under construction.

58. China has 12 photovoltaic manufacturing plants, with a production capacity of 4.5 MWp per annum, but output was only about 550 kWp in 1989. Output is small relative to capacity, because there have been no significant government-sponsored projects, as in India.

59. Market development is the most important requirement if the use of photovoltaics is to expand. The approximate world output of photovoltaic modules for 1976-1989 is shown in table 10. Output in 1989 is expected to be 44 MWp.

Table 10. Approximate output of photovoltaic modules, 1976-1989

Year	Output (MWp)	Year	Output (MWp)
1976	1	1983	20.1
1977	1.5	1984	24.7
1978	2	1985	24.1
1979	2.3	1986	27.4
1980	3	1987	28.1
1981	5	1988	31.5
1982	5.2	1989	44

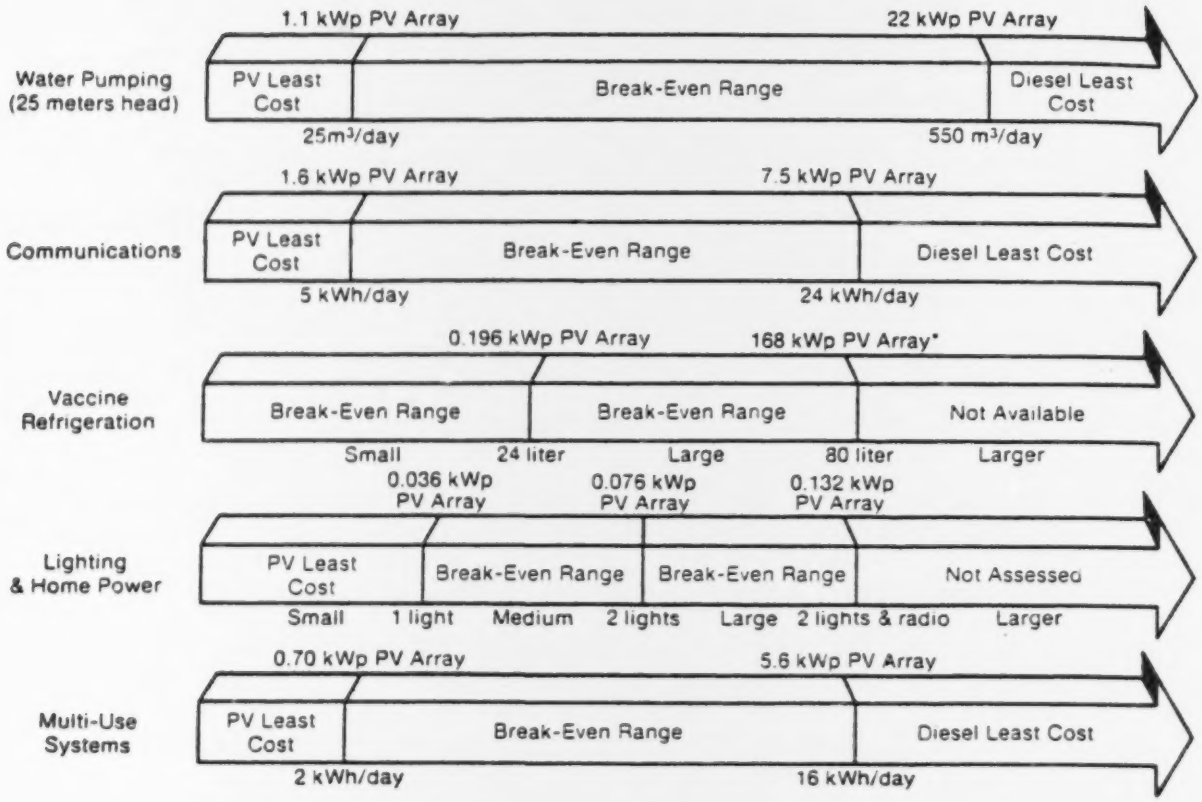
V. CONCLUSIONS AND RECOMMENDATIONS

60. Except for photovoltaic cell costs, which continue to fall steadily, there are few remaining technical obstacles to the eventual widespread utilization of the direct conversion of solar energy into electricity.

61. There are many applications (see chap. II) in which photovoltaic power is an economically competitive choice (fig. IV). 19/ Even though photovoltaic power has advantages over other technologies and is econonomically viable, major efforts are still required before it will be accepted and make an impact on the market.

62. A strategic approach to development should be adopted to use the limited resources of finance and technical skills to achieve a significant use of photovoltaics in developing countries. The ultimate objective would be to introduce suitable systems into the community on a commercial basis, with or without governmental subsidies. The full process would involve:

Figure IV. Economic ranges for photovoltaic systems



(a) Research to identify the basic physical principles, materials and designs;

(b) Laboratory-based development work to adapt system designs to suit local materials and needs, to characterize performance under local conditions and to identify how performance can be improved;

(c) Field work on pilot plants to demonstrate and test representative systems under realistic field conditions, preferably when used by local people such as villagers or farmers;

(d) Full-scale demonstration plants, with prototype commercial units installed at a number of representative sites throughout the country, with the full involvement of the industrial interests and continued technical support from the research institution responsible for the original development;

(e) Commercialization, with local manufacture/assembly of systems and associated marketing and follow-up activities.

63. Photovoltaic projects must be considered along with other development projects and ranked in order of the net benefits likely to accrue to the country as a whole, taking into account both economic and social benefits. The effects a project would have on matters such as employment, food production, balance of payments and development of national skills and self-reliance need to be assessed. The possibilities for local manufacture and assembly of as much of the photovoltaic system as practicable need to be considered.

64. These matters are not easy and straightforward to evaluate. It is, nevertheless, important to appreciate that the viability of photovoltaic projects should not be assessed simply in terms of economics or major energy substitution. For example, the energy requirements for telecommunications are relatively small, but the benefits that can result from installing reliable photovoltaic generators can be of very great significance.

65. Each developing country needs to assess its own needs and institute a staged development for each photovoltaic application of interest, taking into account the status of development reached in similar situations elsewhere. An essential requirement is to build up the necessary institutional support with the skills and finance needed to implement the programme.

66. The market for photovoltaic systems is still very small compared to its potential. The most pressing need is market-building. In order for the industry to survive, grow and thrive, real commercial markets should be opened and developed.

67. Self-sustaining commercial markets for renewable energy systems can be developed by identifying and quantifying the principal barriers that must be overcome. Manufacturers, development assistance agencies and Governments must invest in market development activities if real markets are to emerge. The highest priority should be to educate critical institutional decision makers in market countries, particularly in development financial institutions, electric utilities and rural electrification programmes, and in ministries that make procurement decisions about photovoltaic-powered systems such as water pumps and health systems.

68. The United Nations Development Programme (UNDP), in an effort to meet the challenge, held three workshops in 1985. Since then, although photovoltaic technology has continued to mature, the developing country markets have not. Currently there are several international agencies supporting and funding photovoltaic projects of various types. Very little attention has been paid to market-building. UNDP action has been welcome but is insufficiently funded. The United Nations International Trade Centre has launched a programme to help photovoltaic manufacturers (initially in Brazil and India) increase their exports. This important development also suffers from limited funding. An extensive and ambitious programme of action should be initiated for building real markets.

Notes*

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* In these notes, "Proceedings ..." refers to Proceedings of the Ninth European Photovoltaics Solar Energy Conference, held at Freiburg, Federal Republic of Germany, in September 1989.

Notes (continued)

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